THE HABITABLE ZONE: A POPULATION-BASED PERSPECTIVE. Andras Zsom[1]
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Introduction: What can we tell about exoplanet habitability if only the stellar properties, planet radius, and the incoming stellar flux are known? The Habitable Zone (HZ) is the region around stars where planets can harbor liquid water on their surfaces. The HZ is traditionally conceived as a sharp region around the star because it is calculated for one planet with specific properties e.g., Earth-like [1] or desert planets [2], or rocky planets with H_2 atmospheres [3]. Such planet-specific approach is limiting because the planets' atmospheric and geophysical properties, which influence the surface climate and the presence of liquid water, are currently unknown but expected to be diverse.

Methods: I outline a statistical HZ description which does not select one specific planet type. Instead the atmospheric and surface properties of exoplanets are treated as random variables and a continuous range of planet scenarios are considered. Various probability density functions are assigned to each observationally unconstrained random variable, and a combination of Monte Carlo sampling and climate modeling is used to generate synthetic exoplanet populations with known surface climates. Then, the properties of the liquid water bearing subpopulation is analyzed (see Fig. 1).

Results: Given our current observational knowledge of small exoplanets, the HZ takes the form of a weakly-constrained but smooth probability function. The model shows that the HZ has an inner edge: it is unlikely that planets receiving two-three times more stellar radiation than Earth can harbor liquid water. But a clear outer edge is not seen: a planet that receives a fraction of Earth's stellar radiation (1-10%) can be habitable, if the greenhouse effect of the atmosphere is strong enough. The main benefit of the population-based approach is that it will be refined over time as new data on exoplanets and their atmospheres become available.

References: [1] Kopparapu et al., Habitable Zones around Main-sequence Stars: New Estimates, ApJ, 2013, 765, 131; [2] Zsom et al., Toward the Minimum Inner Edge Distance of the Habitable Zone, ApJ, 2013, 778, 109; [3] Pierrehumbert & Gaidos, Hydrogen Greenhouse Planets Beyond the Habitable Zone, ApJL, 2011, 734, L13

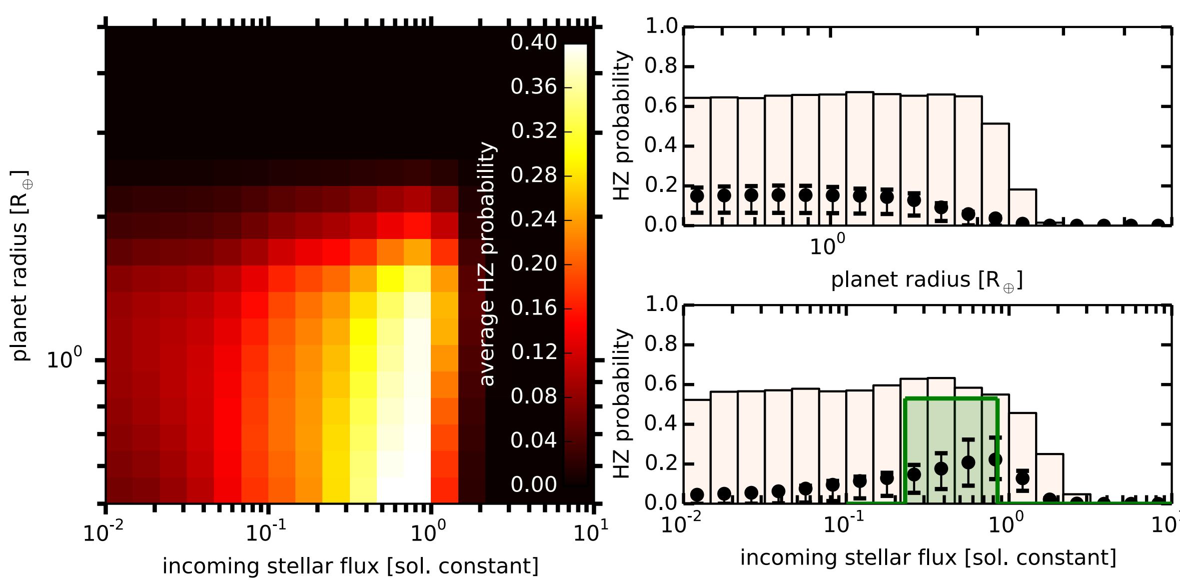

Fig. 1. — *Left:* Average probability of habitability as a function of incoming stellar flux and planet radius for planets orbiting M dwarfs. The average probability that a planet with 1 Earth radius and 1 solar constant incoming stellar flux harbors liquid water is 40%. The uncertainty is large: the probability ranges between 0 and 70% because the atmospheric and surface properties of exoplanets are unconstrained. *Top-right:* Probability of habitability as a function of planet radius only. The black dots are the average values, the error bars depict 25 and 75 percentiles, the shaded columns depict the minimum and maximum probabilities encountered in the model. *Bottom-right:* Probability of habitability as a function of incoming stellar flux with similar symbols as in the figure above. The green shaded region indicates the Earth-like HZ [1] assuming that planets smaller than 1.7 $R_\oplus$ have solid surfaces.